High Temperature Superconductivity Space Experiment (HTSSE)

BANDPASS FILTER IMPROVEMENT EFFORT

Contract Number: N00014-91-C-2056

Final Technical Report

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Novel filter configurations utilizing dielectric resonators in combination with High Temperature Superconductors (HTS) were successfully developed and flight qualified for the High Temperature Superconductivity Space Experiment (HTSSE). All program goals were met and the developed filters exhibit the best electrical performance (extremely low insertion loss) reported to this date.

Filters and resonator configurations developed on this problem have the potential for extremely hig Q factors (in the the order of tens of millions) when very low loss, high dielectric constant materials such as sapphire (or similar compounds) are used. Higher power handling and precise tuning of the filters is also possible.

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1.0 BACKGROUND

Space Systems/Loral (formerly the Space Systems Division of Ford Aerospace), as participants in the High Temperature Superconductivity Space Experiment (HTSSE), delivered 10 flight model devices to NRL for HTSSE I. The delivered devices exhibit performance superior to any superconducting microwave filters reported up to that time. The design and performance of those 10 filters is documented in the final report for contract number N00014-89-C-2248 entitled "Hybrid HTS/Dielectric Resonator Bandpass Filter".

It was felt that with a relatively minor re-design the performance of the flight model filters for HTSSE could be significantly improved. This report documents the re-design efforts and the measured performance results of those efforts. The filters resulting from this re-design effort exhibit performance superior to any superconducting microwave filter reported to date.

Since the effort documented in this report is a continuation of the work done on the 10 flight models delivered for HTSSE, this report extensively references the final report delivered for contract number N00014-89-C-2248 which is hereafter refered to as Reference 1.

2.0 INTRODUCTION

High temperature superconductors hold great potential for the reduction of size, mass, and cost of satellite based microwave components and subsystems, while at the same time offering dramatically improved performance. The High Temperature Superconductivity Space Experiment (HTSSE) program has served to accelerate the development of practical HTS based microwave components for space and other applications. The work documented in this report represents a significant advancement in the state-of-the-art for superconducting microwave filters.

A typical communication satellite may include well over one hundred bandpass filters in input and output multiplexers and other miscellaneous functions. The performance of these filters is critical and for many parameters may dictate the performance of the overall communication channels. High temperature superconductivity offers the potential to

dramatically improve the performance of satellite filters, thereby improving the performance of the overall channel.

Size and mass of satellite filters are also important parameters which can be greatly reduced through HTS realizations. Given the numbers of filters involved on a typical communication satellite, reductions in the size and mass of filters can have a very substantial effect on the launch cost of the satellite.

The current state-of-the-art for satellite filter technology is the use of invar cavity and dielectric loaded cavity filters. For the HTSSE program, we selected an approach which is an adaptation of the dielectric loaded cavity filters currently used in satellites. This approach offers a number of advantages over the conventional dielectric loaded cavity including the following. These advantages are documented in Reference 1.

- Decreased size and mass

- Dramatic performance improvements as a result of the following effects
  - The resistive losses from the cavity walls are nearly eliminated as a result of the low loss superconductors
  - The dielectric losses associated with the dielectric resonators is at least an order of magnitude lower at cryogenic temperatures as compared to room temperature.

The hybrid dielectric/superconductor resonator approach also has a number of advantages as compared to planar superconductor filters including the following.

- No patterning of HTS films is required

- Higher filter quality factors (Q) and, hence, higher performance can be achieved

- Either thin film or bulk superconductors can be used. In fact any superconductor can be used making it easy to select whichever material offers the highest performance.

- Higher power handling capability before experiencing performance degradation

- Tunability can be achieved much more easily.

As mentioned in Section 1.0 of this report Space Systems/Loral developed the hybrid HTS/dielectric resonator filter concept for HTSSE and delivered 10 flight model devices. The measured performance results of the 3-pole, post resonator filters delivered among those 10 is summarized in Table 2-1 below. A photograph of one of those filters is shown in Figure 2-1, and the measured performance for the best performing of those filters is shown in Figure 2-2.

FILTER PART NUMBER	CENTER FREQUENCY	20 dB USABLE BANDWIDTH	INSERTION LOSS	RETURN LOSS
FAC A-01	9.225 GHz	127 MHz	0.21 dB	22 dB
FAC A-02	9.225 GHz	124 MHz	0.58 dB	30 dB
FAC A-03	9.215 GHz	85 MHz	0.25 dB	23 dB
FAC A-04	9.217 GHz	118 MHz	0.22 dB	23 dB
FAC A-05	9.235 GHz	96 MHz	1.24 dB	27 dB

Table 2-1: Summary of the Performance Characteristics of the 3-Pole Filters Delivered for HTSSE I

While the filter performance shown in Figure 2-2 is outstanding, this report documents the minor design modifications implemented to achieve significantly superior performance.

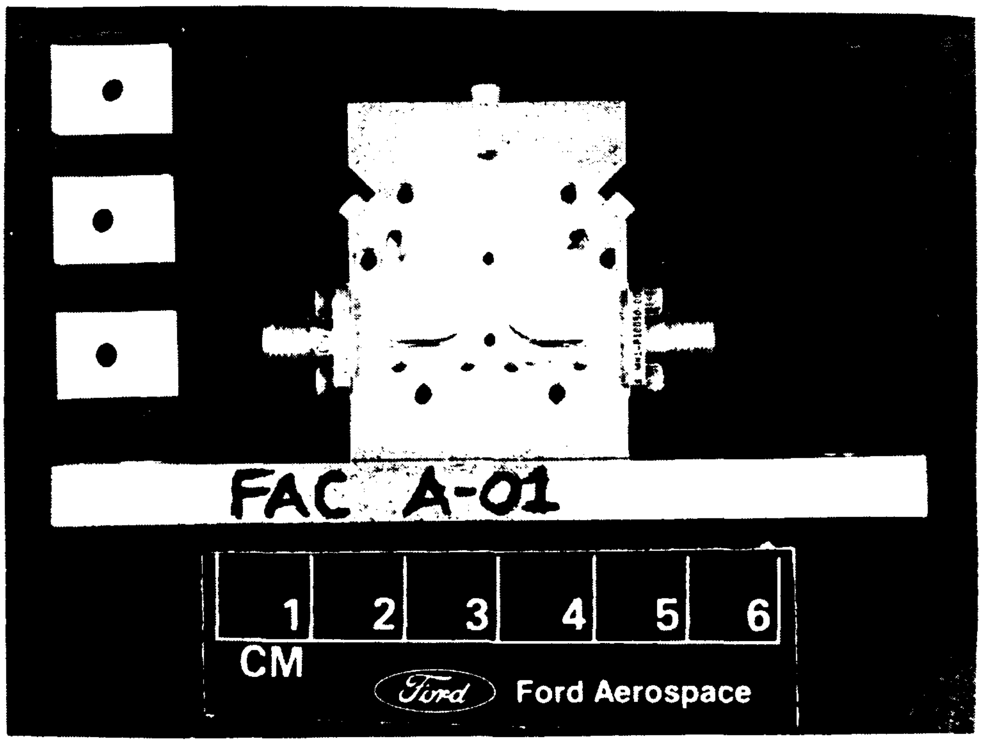

Figure 2-1: Photograph of One of the Original Flight Model Filters Delivered For HTSSE

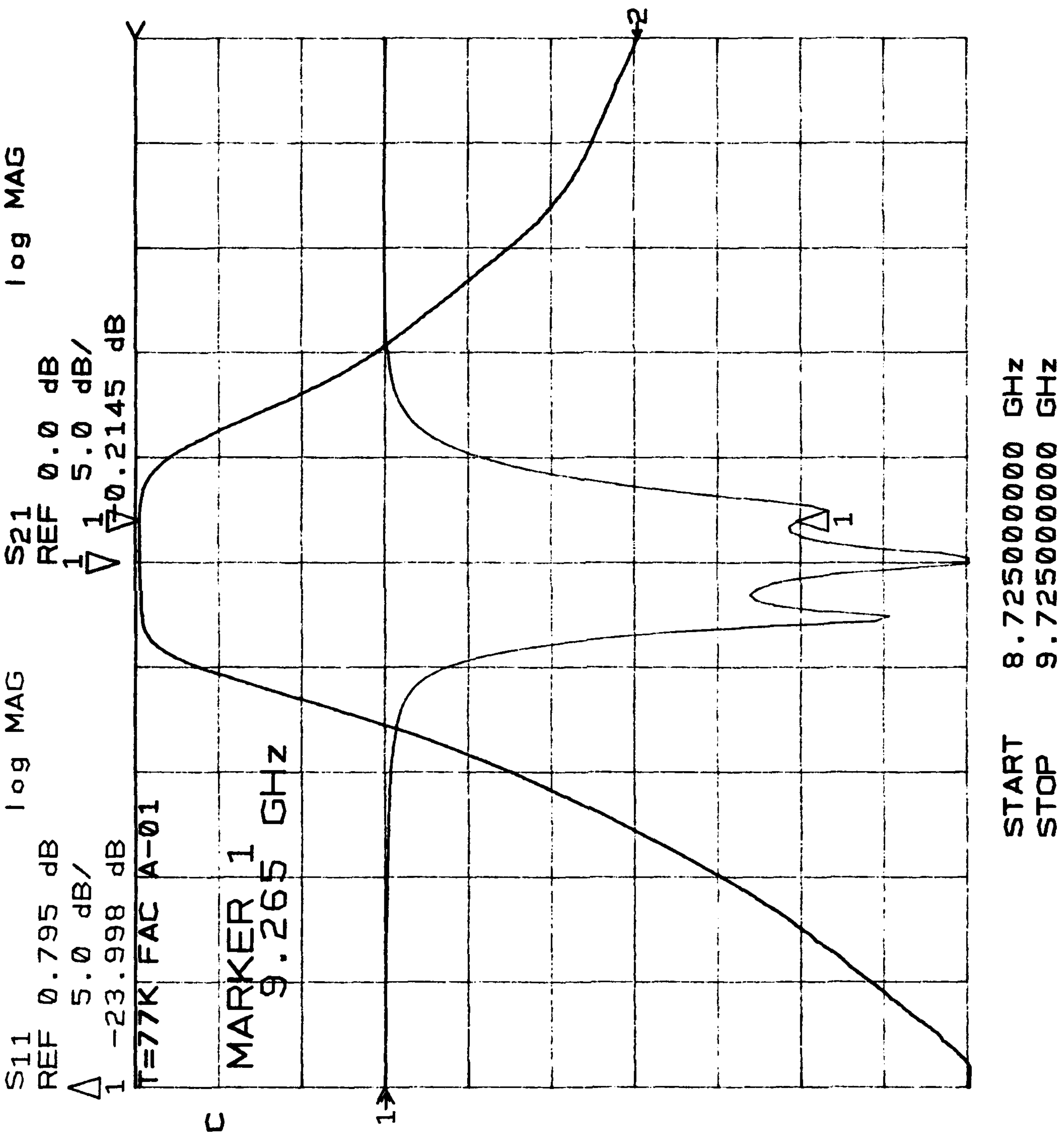

Figure 2-2: Measured Insertion Loss and Return Loss of One of the Original Flight Model Filters Delivered For HTSSE

3.0 DESCRIPTION OF ACHIEVEMENTS

There are 4 contributions to the quality factor (Q) and insertion loss of the hybrid HTS/dielectric resonator filters as listed below.

- The dielectric resonators themselves - This contribution to the loss is minor at cryogenic temperatures. As documented in Reference 1, these resonators have Q factors on the order of 150,000 at 77 Kelvin.

- The retainers designed to hold the dielectric resonators in place - The contribution to the loss from this component is minimized by minimizing the quantity of the material used, and by selecting a low loss material, in this case Rexolite.

- The conductive end plates in the post resonator configuration - This is the dominant component of the loss in a conventional realization. However, in the superconducting case, this component of the loss approaches zero.

- The conductive walls of the filter housing - This component of the loss can be reduced by using a low resistivity material, i.e. copper, and by increasing the distance from the dielectric resonator to the the housing walls.

In the improved performance filters described in this report, efforts were taken to minimize the loss contributions from each of the effects described above. The most significant differences in the improved performance filters described in this report as compared to the flight models delivered for HTSSE are the following.

- The housing walls were designed to be at a greater distance from the dielectric resonator pucks, hence, reducing the negative impact on Q.

- The Rexolite retainers were re-designed to require less material, hence, reducing the negative impact on Q.

- The improved performance filters were designed to have a narrower bandwidth to highlight the superior performance.

- The improved filters were manufactured from HTS films having surface resistance values approximately 1/20 that of copper at 77K. The films used were manufactured by Conductus Inc. using off axis sputtering. These films were YBCO on Lanthanum Aluminate. The microwave properties of the films used in these devices are comparable to those used in the originally delivered flight units.

Figure 3-1 shows a photograph of the filter resulting from the re-design effort. Figures 3-2 and 3-3 show the measured performance of the re-designed filter. The performance characteristics of the filter at 77 K are as follows.

- Center Frequency: 9.6 GHz
- 20 dB Return Loss Bandwidth: 45 MHz
- Insertion Loss: 0.09 dB
- Return Loss: 28 dB
- Number of Poles: 3
- Calculated Equivalent Q Factor: Approximately 30,000

As illustrated by the data summarized above, the performance of the re-designed filters was significantly improved as compared to the 10 flight models originally delivered for HTSSE. This performance is significantly superior to that of any superconducting microwave filter reported in the literature to date. Unfortunately, this filter was not completed in time for the space experiment.

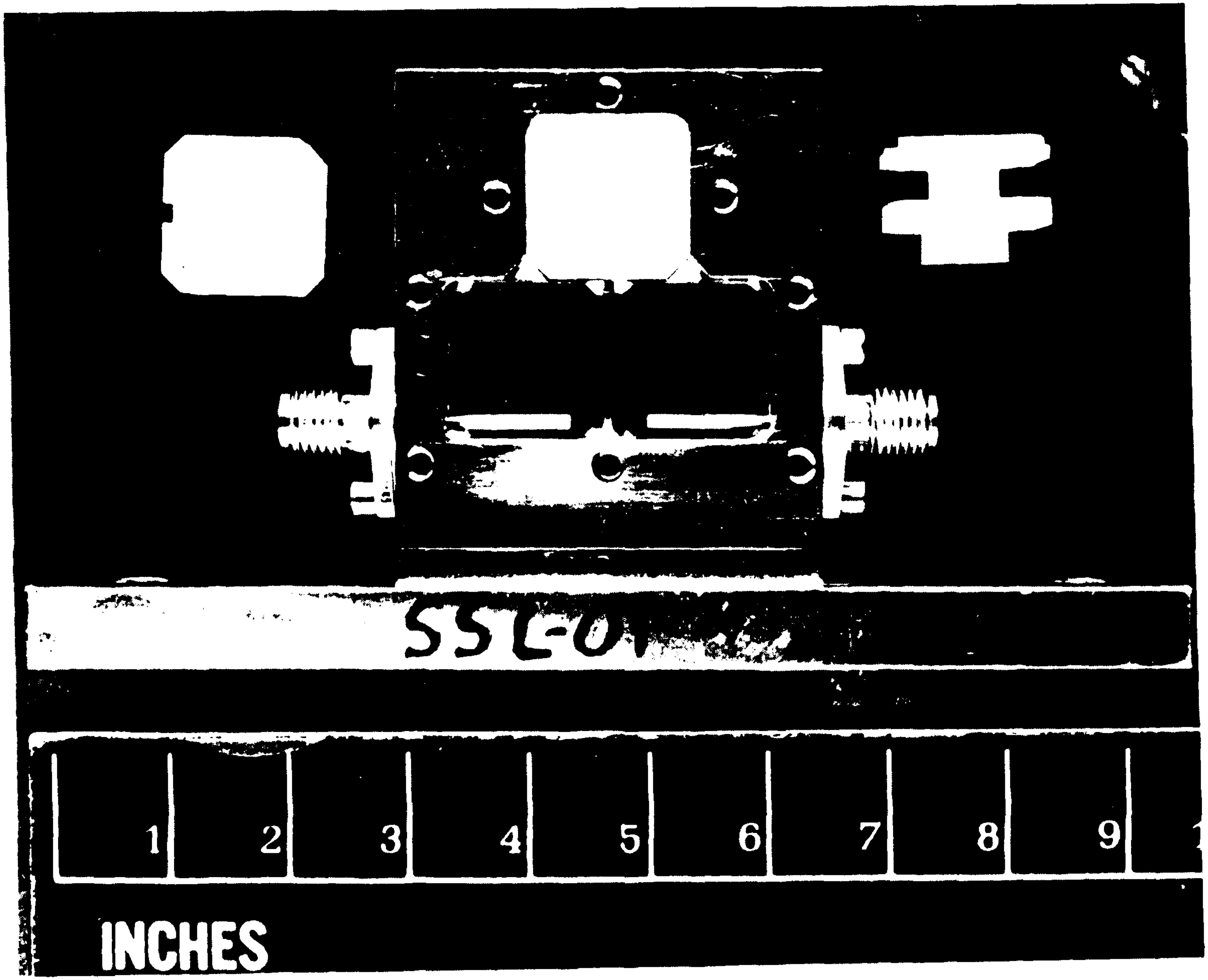

Figure 3-1: Photograph of the Improved Performance Filter Resulting From The Re-design Effort Completed Under This Contract

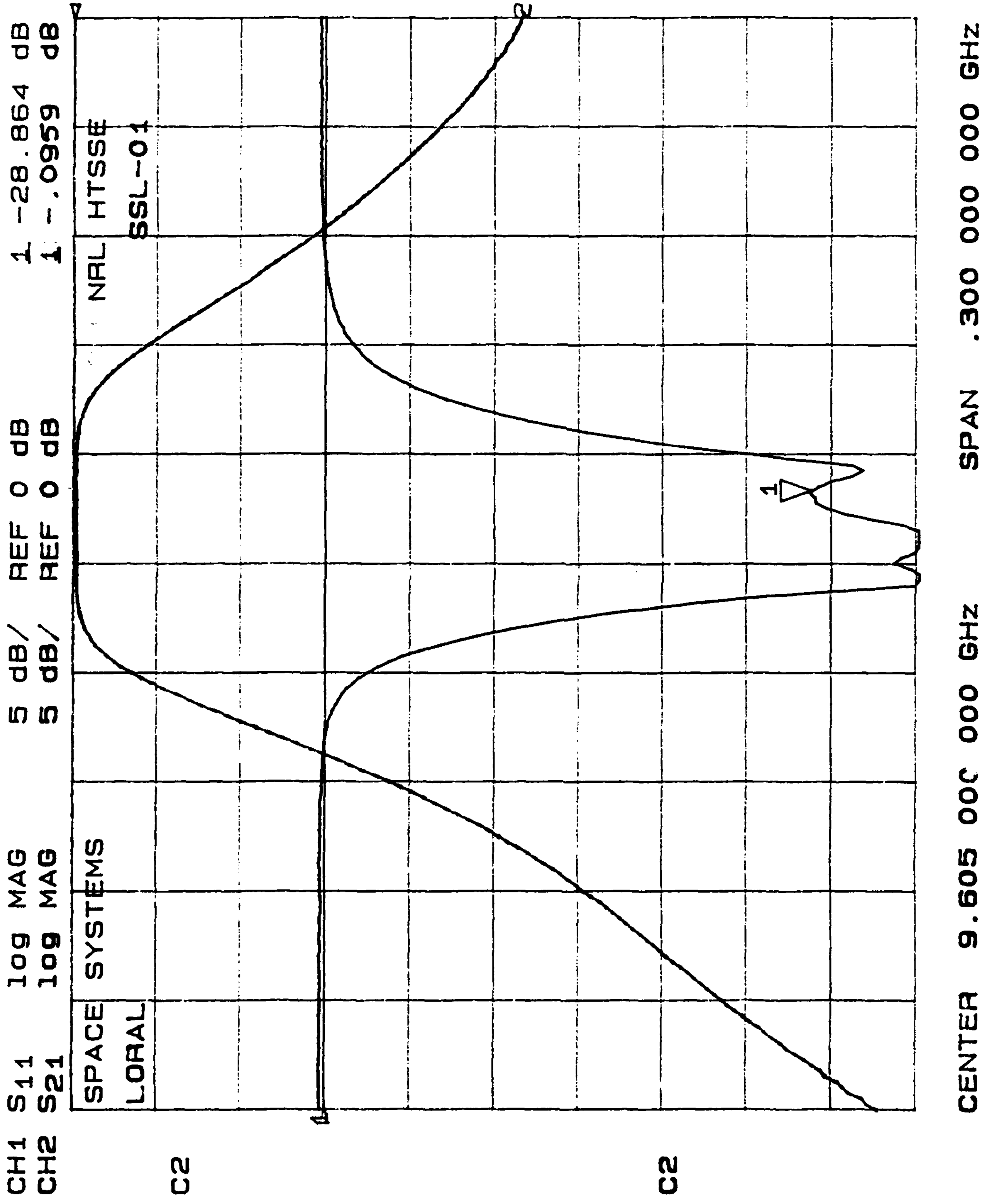

Figure 3-2: Measured Insertion Loss and Return Loss Performance of the Improved Performance Filter. This Performance Represents the Best Performing Superconducting Filter Reported to Date.

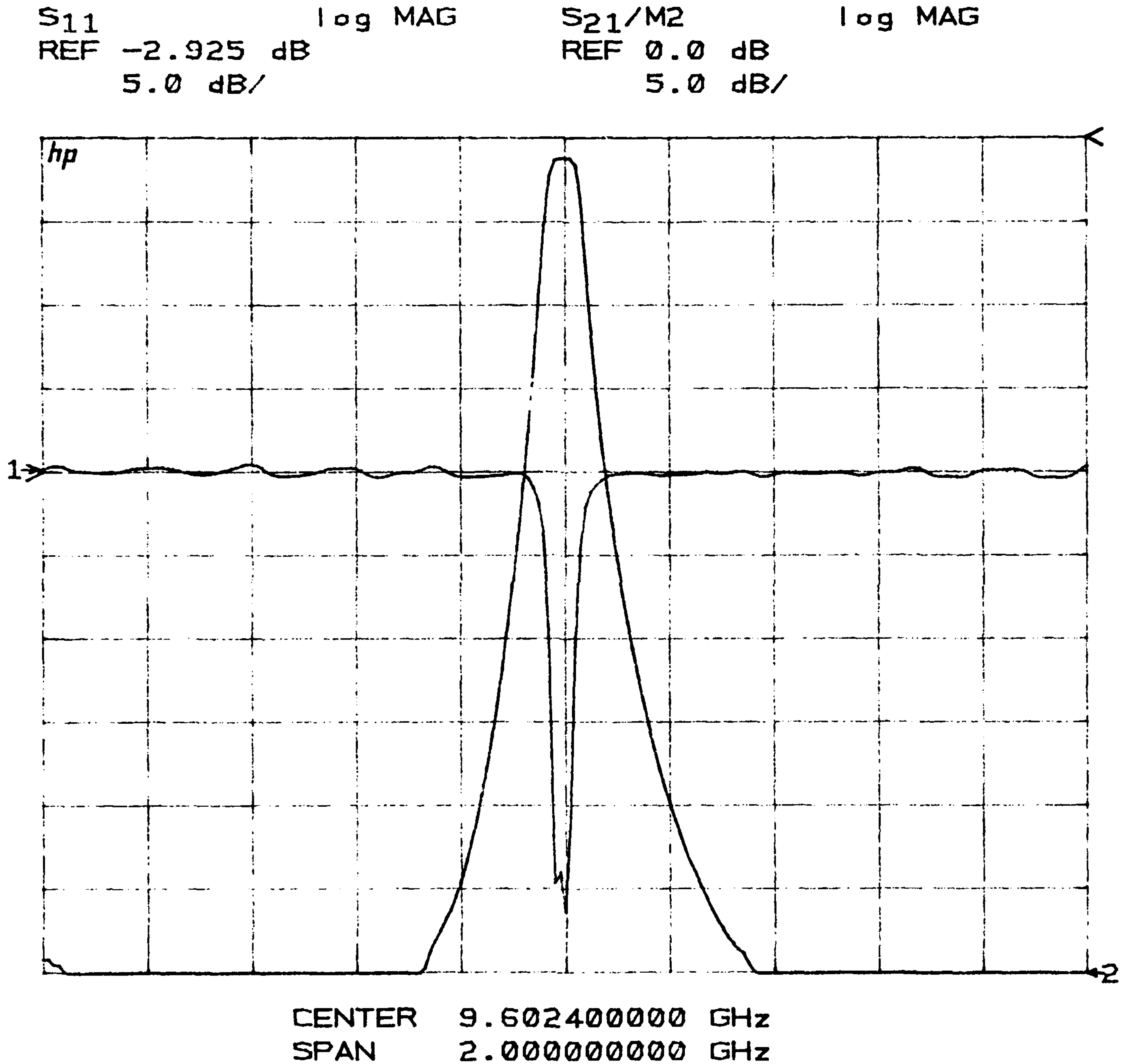

Figure 3-3: Measured Rejection Characteristics of the Improved Performance Filter.

4.0 SUMMARY AND CONCLUSIONS

In this program, the novel, hybrid HTS/dielectric resonator filter configurations developed for the High Temperature Superconductivity Space Experiment were significantly improved by implementing minor modifications to the physical package. Further performance improvements can be achieved by making the dielectric resonators from sapphire as opposed to the ceramic materials used in the filters documented here. The performance could also be slightly improved by designing the housing to have superconducting walls.

The resultant filters have important advantages over the conventional filters currently used for satellite communications and over other superconducting filter configurations. The results documented in this report represent significant advances toward the practical application of high temperature superconductivity to satellite communications.

During the time period the work described in this report was being performed, Space Systems/Loral invented a series of new and novel superconducting filter configurations as part of an ongoing IR&D project. These new filter configurations offer the potential for significant improvements above those documented in this report. Two publications describing these new filter configurations are reprinted in the Appendices of this report.

APPENDICES

APPENDIX A

REPRINT OF THE PAPER ENTITLED "MINIATURE DUAL MODE PLANAR FILTERS"

MINIATURE DUAL MODE MICROSTRIP FILTERS

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Space Systems/Loral
Palo Alto, California

ABSTRACT

Dual mode cavity and dielectric resonator filters are the mainstay of satellite communications. In this paper, a new generation of planar dual mode filters is introduced which offers significant size, weight, and cost advantages over these previous designs. All currently used elliptic function, self equalized, etc. filter designs can be implemented in microstrip using this new concept. The proposed filter structures are ideally suited for implementation using the recently discovered high temperature superconductors. Basic dual mode resonator and filter structures are discussed, and experimental data for proof of concept filters implemented using both normal and superconducting microstrip are presented.

INTRODUCTION

Design techniques for single mode microstrip filters such as broad side edge coupled filters have long been established. However, these filters are of limited utility for most high performance microwave applications due to their typically high insertion loss and impracticality for filter pass bands of less than 5%. The high performance requirements for communication satellite frequency multiplexers typically require the use of dual mode cavity or dielectric resonator filters to realize self equalized, quasi-elliptic responses having pass bands often less than 1%. Cavity and dielectric resonator filters have the the drawbacks of relatively large size and high cost.

In this paper, we introduce a new class of dual mode planar filters that are ideally suited for the realization of narrow band, quasi-elliptic, and self equalized responses and offer significant size, weight and cost reductions as compared to cavity and dielectric resonator designs. This new class of filters, based on (1), is especially well suited for implementation using extremely low loss, thin film, high temperature superconductors. Here we present a variety of dual mode microstrip resonator and filter structures as well as measured data for proof of concept filters based on this concept.

DUAL MODE MICROSTRIP RESONATOR STRUCTURES

Figure 1 illustrates three dual mode microstrip resonator structures that are the building blocks of a new class of dual mode planar filters. In each of these structures, a perturbation has been added to a previously single mode resonator at a point that is 45 degrees from the axes of coupling to the resonator. The perturbation in the symmetry of the resonator at the 45 degree offset location facilitates coupling between two orthogonal modes within the resonator. The axes of coupling to the resonator are orthogonal, so each couples energy independently to and from only one of the orthogonal modes within the resonator as is required to realize dual mode filters of more than two poles. The perturbations can take on any number of forms, and the extent to which they disturb the resonant fields, determines the coupling coefficient between the two orthogonal modes. The perturbations shown in Figure 1 were chosen because of their repeatability, symmetry, and tunability.

The square resonator of Figure 1 is an adaptation of a single mode resonator commonly used for microstrip patch antennas and previously used as a discriminator (2,3). The circular resonator is an adaptation of a single mode disk resonator that is also used in microstrip antennas and has been used previously to realize single mode microstrip filters (2,4). The dual mode ring resonator is an adaptation of the single mode resonator commonly used for a variety of

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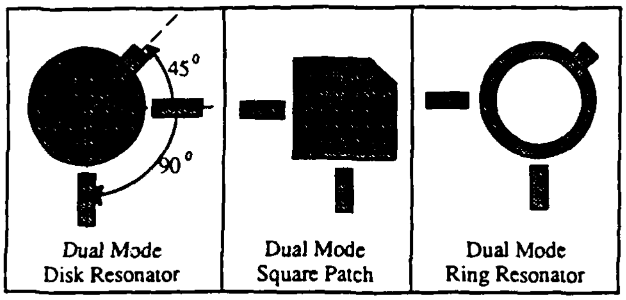

Figure 1: Three dual mode microstrip resonators that are the building blocks for a new class of planar dual mode filters.

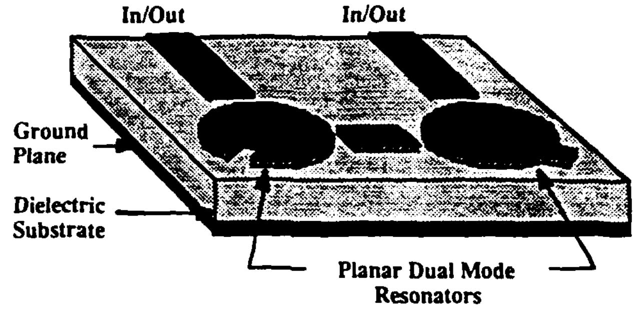

Figure 3: Realization of a dual mode, four pole, Chebyshev, microstrip filter using disk resonators.

purposes including microstrip transmission line evaluation. Perturbations in ring resonators have been used previously to excite degenerate modes, but to our knowledge have not previously been used to to realize multi-pole (n>2) dual mode filters (5,6).

DUAL MODE MICROSTRIP FILTER CONFIGURATIONS

The resonators described in the previous section can be arranged in a number of ways to realize dual mode microstrip filters. In this section, we present a few of the feasible configurations. The sketch in Figure 2 illustrates a dual mode, four pole, Chebyshev filter realized using two square patch resonators. The arrows represent the dual orthogonal modes facilitated by the asymmetric "cut away" corner geometry. Coupling to and from the resonators is facilitated by capacitive microstrip gaps, and the coupling between the orthogonal modes is a result of the asymmetry. A similar four pole filter realized using dual mode microstrip disk resonators is illustrated in Figure 3.

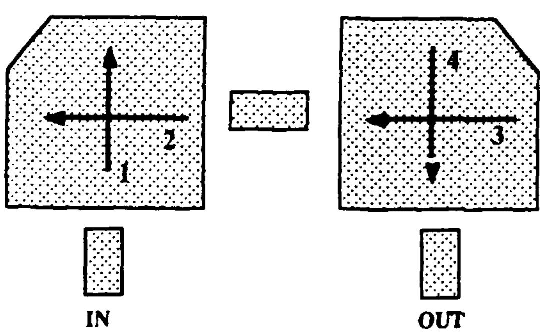

Figure 2: Sketch of a dual mode, four pole, microstrip filter. The arrows represent the orthogonal modes within the resonators.

One of the principle advantages of this new class of planar filters over other classes of microstrip filters is that it facilitates the practical realization of elliptic and quasi-elliptic function responses. Figures 4 and 5 illustrate two dual mode microstrip realizations of elliptic function filters. The required cross coupling is implemented using short sections of microstrip.

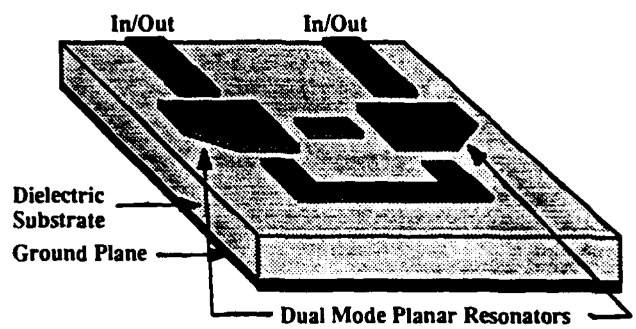

Figure 4: Four pole, dual mode, elliptic function microstrip filter using square patch resonators.

Figure 5: Realization of an eight pole, dual mode, elliptic function, microstrip filter.

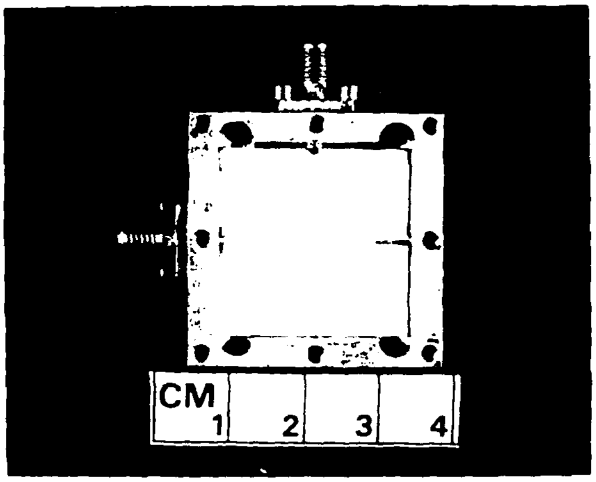

Figure 6: Photograph of two pole, dual mode POC filter.

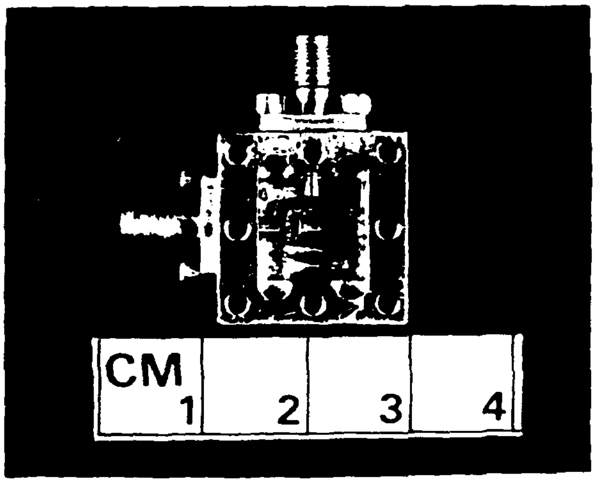

Figure 8: Photograph of a dual mode, superconducting, ring resonator filter.

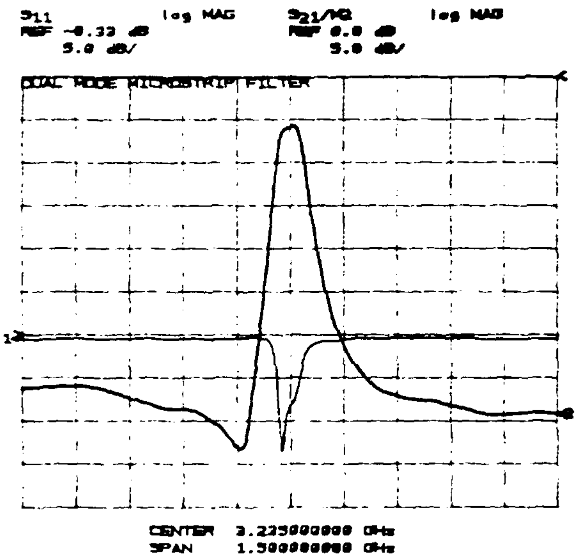

Figure 7: Measured performance of the filter shown in Figure 6 illustrating two well defined poles.

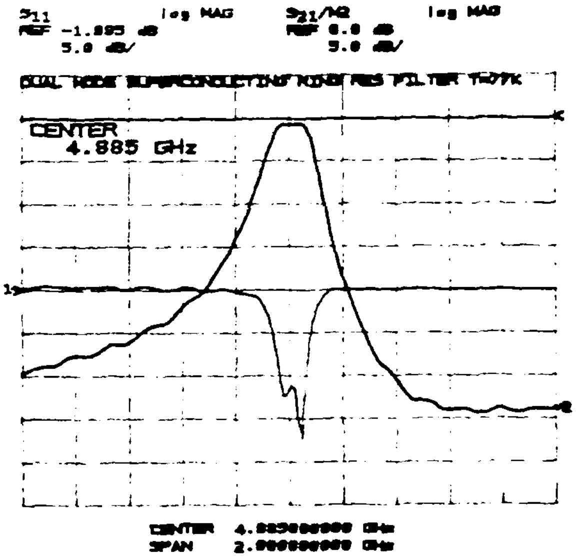

Figure 9: Measured performance of the filter shown in Figure 8 at 77K. Superconductors may be used to fabricate high Q, dual mode, microstrip filters.

EXPERIMENTAL RESULTS

Proof of concept (POC) filters using both normal (copper/gold) and thin film superconducting microstrip have been fabricated to demonstrate this concept. Figure 6 is a photograph of a dual mode, POC, two pole filter realized using a square patch resonator, and Figure 7 is a plot of its measured performance. In this filter, the asymmetrical perturbation is implemented by using a checker board pattern in the metallization at one corner of the patch.

Figure 8 is a photograph of a 2 pole, dual mode, ring resonator filter that was implemented using the high temperature superconductor YBCO on a lanthanum aluminate substrate. Coupling between the orthogonal modes is implemented by the silver stub on the ring. Figure 9 is a plot of the performance of this POC filter measured at at 77 Kelvin. As compared with an identical

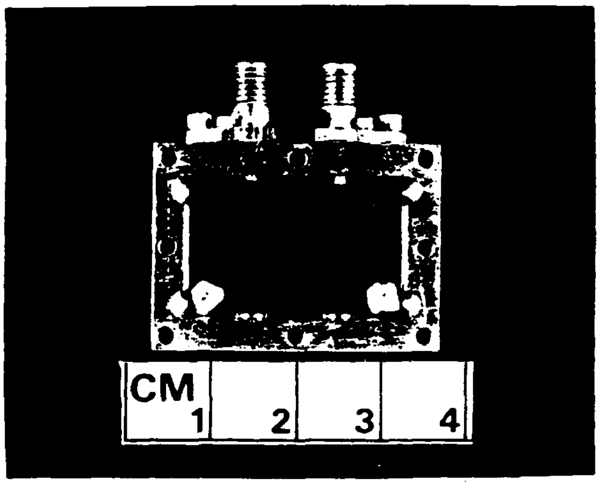

Figure 10: Photograph of a four pole, dual mode microstrip filter that is currently being optimized.

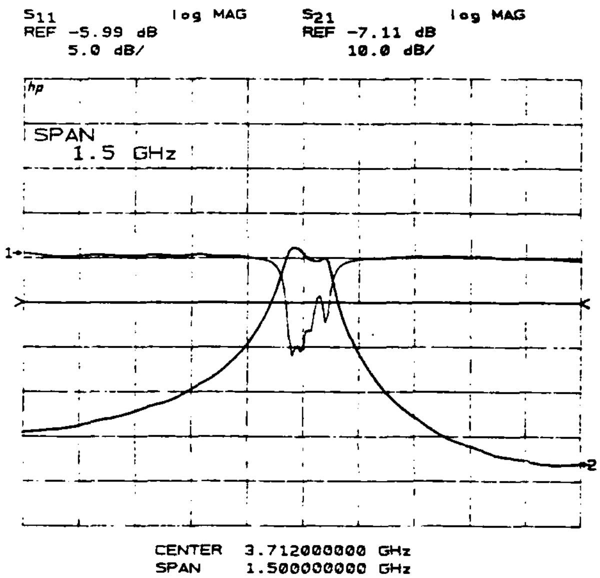

Figure 11: Measured performance of the filter shown in Figure 10. The four well defined poles illustrate the dual mode behavior of the device.

circuit fabricated from a normal metal microstrip, this superconducting filter exhibits more than a 3 dB improvement in insertion loss.

Figure 10 is a photograph of a 4 pole, dual mode microstrip filter on lanthanum aluminate that is currently being optimized. Figure 11 illustrates the initial performance of this filter showing 4 well defined poles. The lanthanum aluminate substrate was chosen so the optimized filter can ultimately be realized using high temperature superconductors. The asymmetrical perturbations required for dual mode behavior were implemented using dielectric tuning elements.

CONCLUSIONS

In this paper we have introduced a new generation of planar dual mode filters. These filters can be used to implement the elliptic function, self equalized, narrow band responses required for satellite communications, but are significantly smaller, lighter, and potentially less expensive than the dual mode cavity and dielectric resonator filters currently used. This new class of filters is ideally suited for fabrication from thin film high temperature superconductors to achieve high Q performance. A variety of these filters has been demonstrated using both normal metal and superconducting microstrip. Superconducting realizations of this new class of filters may be used to replace bulkier, heavier filters currently used for satellite communications.

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APPENDIX B

REPRINT OF THE PAPER ENTITLED "DUAL MODE PLANAR FILTERS"

Dual Mode Microstrip Filters

A new generation of planar, dual mode filters is introduced which offers significant size, weight, and cost advantages over previous designs.

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Palo Alto, California

Dual mode cavity and dielectric resonator filters are the mainstay of satellite communications. In this paper, a new generation of planar, dual mode filters is introduced which offers significant size, weight, and cost advantages over these previous designs. All currently used filter designs, such as elliptic function, self equalized, and other common types can be implemented in microstrip using this new concept. The proposed filter structures are ideally suited for implementation using the recently discovered high temperature superconductors. Basic dual mode resonator and filter structures are discussed, and experimental data for proof of concept filters implemented using both normal and superconducting microstrip are presented.

Previous dual mode filters for microstrip were limited to 5% bandwidth.

Design techniques for single mode microstrip filters such as those illustrated in Figure 1 have long been established. However, these filters are of limited utility for most high performance micro-

Figure 1. Illustrations of commonly used, single mode microstrip filter configurations. On the left is the broadside edge coupled configuration, and the interdigital configuration is on the right.

wave applications due to their typically high insertion loss and impracticality for filter pass bands of less than 5%. It is also very difficult, if not impractical, to realize self equalized, elliptic function responses using these single mode structures. Figure 2 illustrates the superior selectivity and insertion loss performance of an elliptic function filter as compared to a Tchebyscheff filter having the same number of poles, and equivalent bandwidths and quality factors.

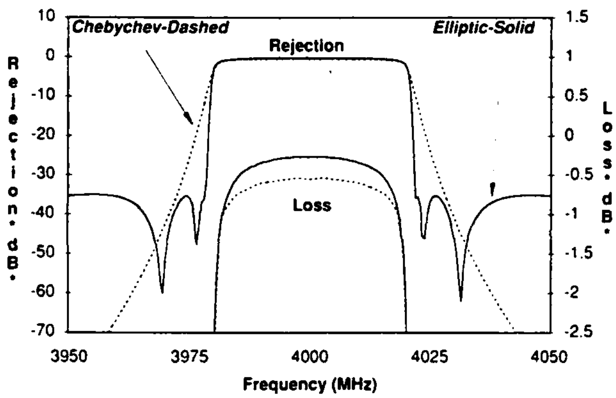

Figure 2. Plots contrasting the performance of Tchebyscheff and elliptic function filters.

The high performance requirements for communication satellite frequency multiplexers typically require the use of dual mode cavity or dielectric resonator filters to realize group delay equalized, quasi-elliptic responses having pass bands often less than 1%. Cavity and dielectric resonator filters have the the drawbacks of relatively large size and high cost as compared to planar filter structures.

In this paper, we introduce a new class of dual mode planar filters that are ideally suited for the realization of narrow band, quasi-elliptic, and self equalized responses and offer significant size, weight and cost reductions compared to cavity and dielectric resonator designs. This new class of filters, based on [1,2], is especially well suited for implementation using extremely low loss, thin film, high temperature superconductors for high performance applications. Here we present a variety of dual mode microstrip resonator and filter structures as well as measured data for proof of concept filters based on this concept.

Dual Mode Microstrip Resonator Structures

Figure 3 illustrates three dual mode microstrip resonator structures that are the building blocks of a new class of dual mode planar filters. Variations of these geometries may also be used to implement dual mode filters. In each of these structures, a perturbation has been added to a previously single mode resonator at a point that is 45 degrees from the axes of coupling to the resonator. The perturbation in the symmetry of the resonator at the 45 degree offset location facilitates coupling between two orthogonal modes within the resonator.

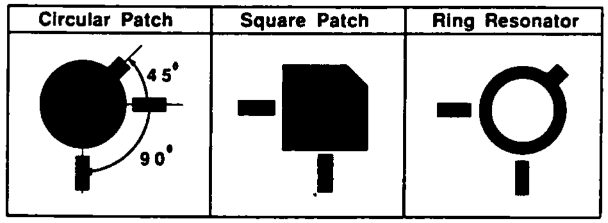

Figure 3. Illustration of three dual mode microstrip resonators that are the building blocks for a new class of planar dual mode filters.

The axes of coupling to the resonator are orthogonal, so each couples energy independently to and from only one of the orthogonal modes within the resonator, as is required to realize dual mode filters of more than two poles. The perturbations can take on any number of forms, and the extent to which they disturb the resonant fields, determines the coupling coefficient between the two orthogonal modes.

The dual mode square resonator is an adaptation of a microstrip patch antenna.

The square resonator of Figure 3 is an adaptation of a single mode resonator commonly used for microstrip patch antennas and previously used as a discriminator [3,4]. The circular resonator is an adaptation of a single mode disk resonator that is also used in microstrip antennas and has been used previously to realize single mode microstrip filters [3,5]. The dual mode ring resonator is an adaptation of the single mode resonator commonly used for a variety of purposes including microstrip transmission line evaluation. Perturbations in ring reso-

nators have been used previously to excite degenerate modes, but to our knowledge have not previously been used to to realize multi-pole ($n > 2$) dual mode filters [6,7].

Coupling energy to and from the dual mode resonators of Figure 3 can be accomplished in a number of ways as illustrated in Figure 4. Variations of these coupling structures can also be used. The capacitive gaps in Figure 4 are well suited for implementing small coupling coefficients; the direct coupled lines work well for large couplings, and the edge coupled lines work well for intermediate coupling coefficients.

Coupling to dual mode resonators can be effected with capacitive gaps as well as both direct and edge coupled lines.

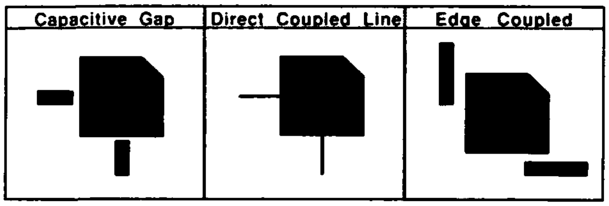

Figure 4. Illustrations of some coupling structures which may be used to couple energy into and out of dual mode microstrip resonators.

Coupling between the dual orthogonal modes within each resonator can also be accomplished using a number of physical perturbations to the resonator symmetry. Some possible perturbations which work well are illustrated in Figure 5. These perturbations were chosen because of their repeatability, symmetry, and tunability. While these structures are shown as examples, a large variety of perturbations may be used.

Intercoupling of the dual modes can be accomplished with physical perturbations to the resonators.

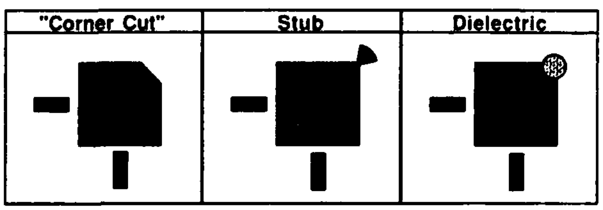

Figure 5. Illustrations of some physical perturbations which may be used to implement the coupling between the orthogonal modes of a dual mode planar resonator.

Dual Mode Microstrip Filter Configurations

The resonator and coupling structures described in the previous section can be arranged in a number of ways to realize dual mode microstrip filters. In this section, we present a few of the feasible configurations. The sketch in Figure 6 illustrates a dual mode, four pole, Tchebyscheff filter realized using two square patch resonators. The arrows represent the dual orthogonal modes facilitated by the asymmetric "cut away" corner geometry. Coupling to and from the resonators is facilitated by capacitive microstrip gaps, and the coupling between the orthogonal modes is a result of the asymmetry.

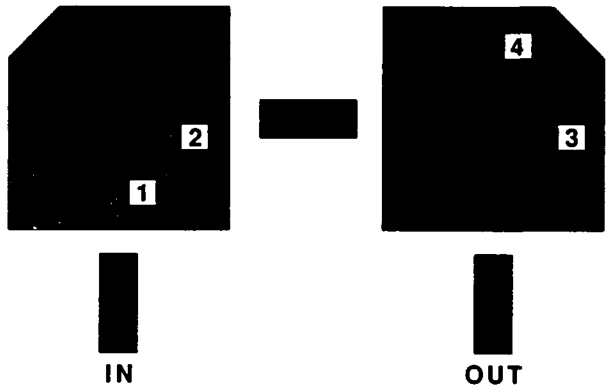

Figure 6: Sketch of a dual mode, four pole, microstrip filter. The arrows represent the dual orthogonal modes within the resonators.

As already noted, one of the principal advantages of this new class of planar filters over other classes of microstrip filters is that it facilitates the practical realization of self equalized, elliptic and quasi-elliptic function responses. Figures 7 through 9 illustrate three dual mode microstrip realizations of elliptic function filters. These figures include illustrations of four and eight pole filters using both square and disk, dual mode resonators. The required cross coupling is implemented using short sections of microstrip transmission line.

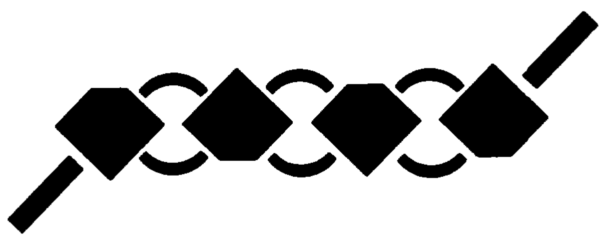

Figure 7. Realization of a four pole, dual mode, elliptic function microstrip filter using square patch resonators.

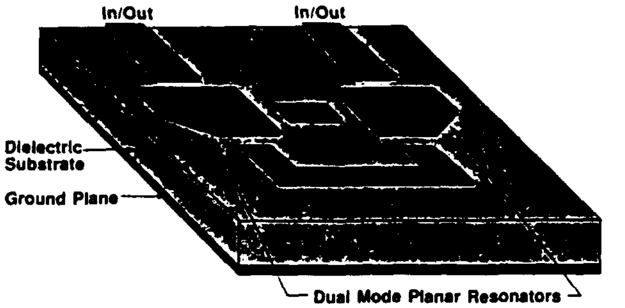

Figure 8. Illustration of a four pole, elliptic function microstrip filter similar to that of Figure 7, implemented using dual mode circular disk resonators.

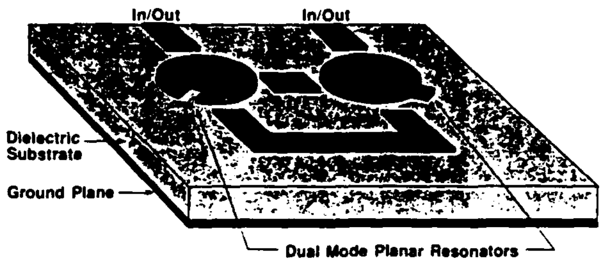

Figure 9. Realization of an eight pole, dual mode, elliptic function, microstrip filter, illustrating how the structures of Figures 7 and 8 can be extended to implement filters of any desired number of poles. This architecture can also be used to implement self-equalized filters.

Experimental Results

Proof of concept (POC) dual mode filters using both normal (copper/gold) and thin film superconducting microstrip have been fabricated to demonstrate the feasibility of this dual mode microstrip filter concept. Figure 10 is a photograph of a dual mode, POC, four pole Tchebyscheff filter realized using two square patch resonators, and Figure 11 is a plot of its measured performance.

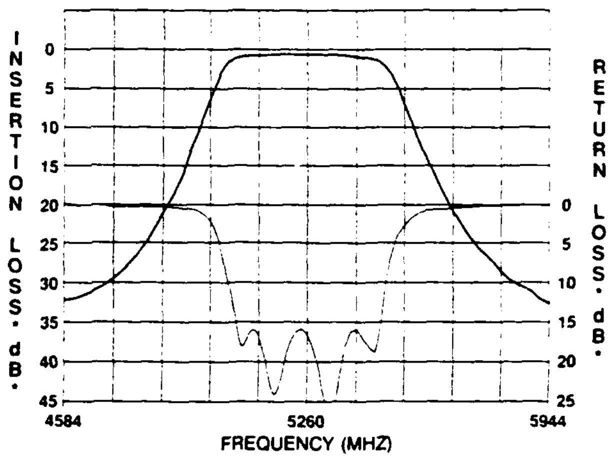

Figure 11. Measured insertion loss and return loss performance of the filter shown in Figure 10.

Figure 12 is a photograph of a four pole, dual mode, elliptic function filter, and Figure 13 is a plot of its measured performance. This filter is implemented using a combination of capacitive gaps and directly coupled lines for coupling between the resonators and the "cut away" corner geometry to facilitate coupling between the orthogonal modes within the resonators. These plots clearly exhibit transmission zeros characteristic of elliptic function performance, illustrating the feasibility of dual mode, elliptic function, microstrip filters.

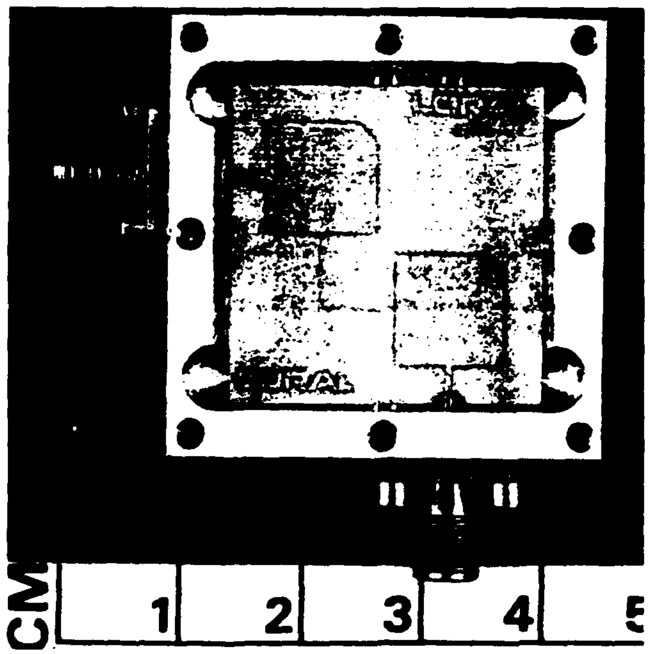

Figure 10. Photograph of a proof of concept, 4-pole, dual mode, filter implemented using copper/gold microstrip on an alumina substrate.

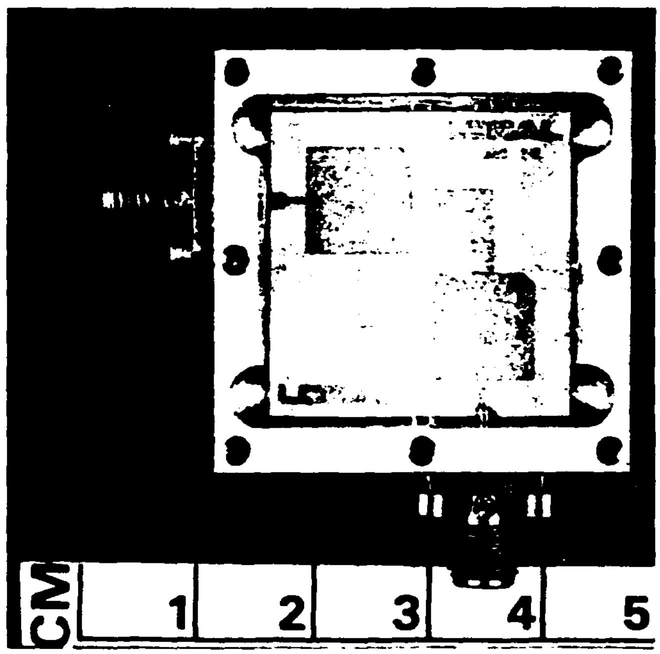

Figure 12. Photograph of a proof of concept, 4-pole, elliptic function, dual mode, filter implemented using copper/gold microstrip on an alumina substrate.

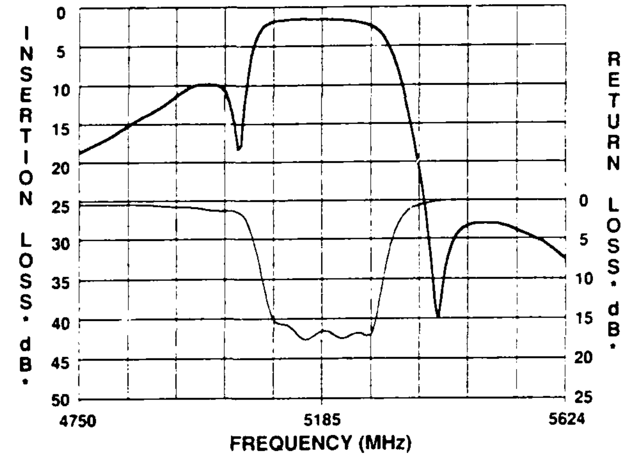

Figure 13. Measured insertion loss and return loss performance of the filter shown in Figure 12.

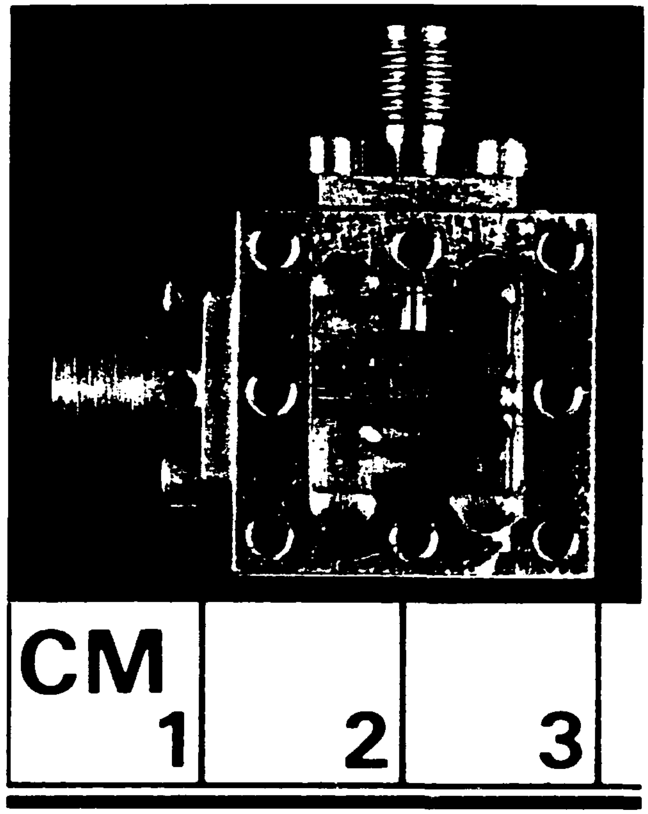

Figure 14. Photograph of a two pole, dual mode, superconducting, ring resonator filter.

The performance plot of Figure 13 exhibits some asymmetry as a result of couplings between nonadjacent poles. This can be corrected by increasing the spacing between the resonators. However, this plot clearly demonstrates the feasibility of dual mode elliptic function filters in microstrip.

Dual mode microstrip filters can use thin film, high temperature superconductors advantageously.

Dual mode microstrip filters can be implemented using thin film superconductors for high performance applications. Figure 14 is a photograph of a 2 pole, dual mode, ring resonator filter that was implemented using the high temperature superconductor YBCO on a lanthanum aluminate substrate. The coupling between the dual orthogonal modes is facilitated by the silver stub on the ring that is located approximately 45 degrees from the axes of coupling to the filter.

Figure 15 is a plot of the performance of this POC filter measured at at 77 Kelvin. As compared with an identical circuit fabricated from a normal metal microstrip, this superconducting filter exhibits more than a 3 dB improvement in insertion loss.

A new class of microstrip resonator has been introduced which is ideally suited for fabrication from thin film, high temperature superconductors to achieve high Q performance. A variety of these filters has been demonstrated using both normal metal and superconducting microstrip. Superconducting realizations of this new class of filters may be used to replace bulkier, heavier, more costly filters currently used for satellite communications as illustrated in Figure 16.

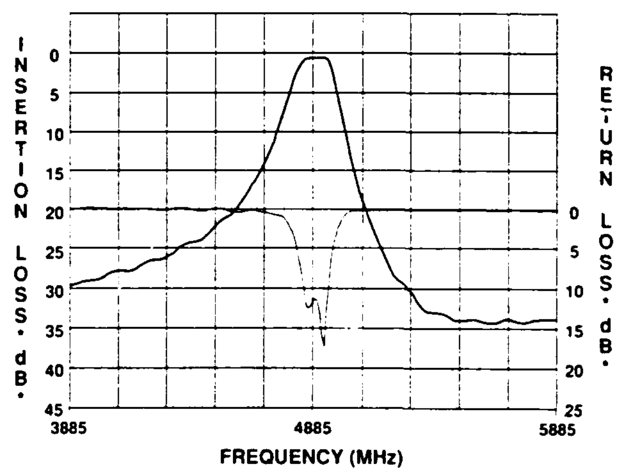

Figure 15. Measured performance of the filter shown in Figure 14 at 77K. Superconductors may be used to achieve high performance, dual mode, microstrip filters.

Each of the filters in Figure 16 operates at C-band and may have performance similar to the others assuming superconducting thin films are used in the microstrip filter. The current technology of choice is dielectric resonator filters because they are relatively small and light in comparison to waveguide post and cavity filters. However, as illustrated in the photograph, superconducting dual mode microstrip filters may offer significantly smaller size and lower mass while at the same time offering significantly lower cost as a result of printed circuit fabrication techniques.

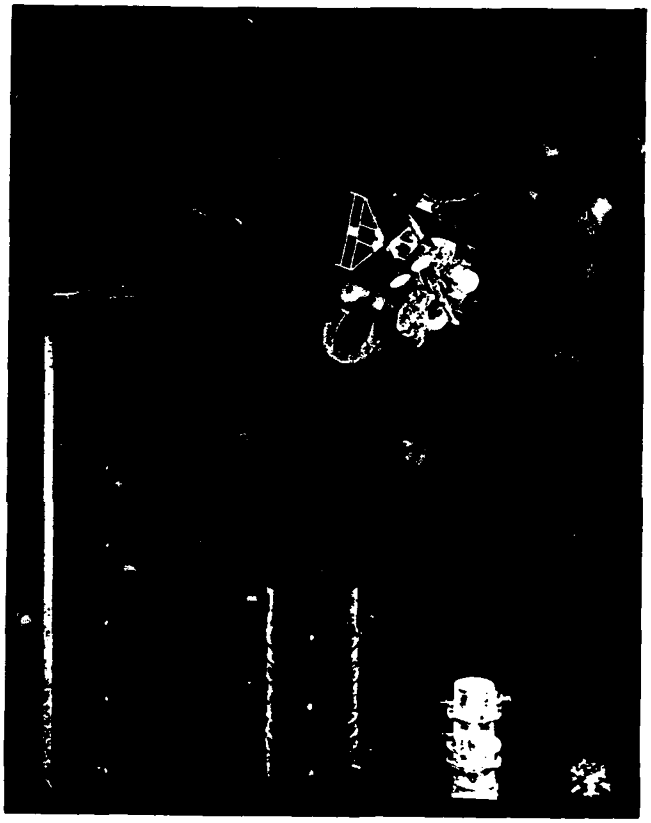

Figure 16. Photograph of some alternative satellite bandpass filter technologies. From left to right are waveguide post filter, dual mode cavity filter, dual mode dielectric resonator filter, and dual mode microstrip filter.

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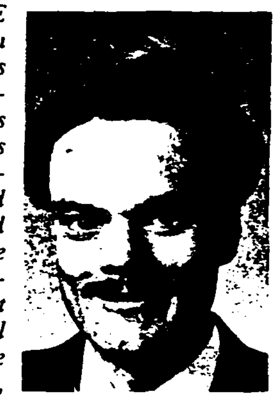

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Mr. Fiedziuszko has served as the Chairman of the Santa Clara Valley Chapter of MTT, and is a member of a number of MTT committees. He holds 7 patents with several pending and has authored numerous papers. He is a recipient of the Ford Aerospace Exceptional Inventor Award and of the Aviation Week, 1990 Laurels Award.